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CONCEPTUAL DESIGN OF THE NSLS-II INJECTION SYSTEM*

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Abstract

We present the conceptual design of the NSLS-II injection system [1, 2]. The injection system consists of a low-energy linac, booster and transport lines. We review two different injection system configurations; a booster located in the storage ring tunnel and a booster housed in a separate building. We briefly discuss main parameters and layout of the injection system components.

INTRODUCTION

The NSLS-II will be a state-of-art synchrotron radiation facility [3] featuring ultra-high photon brightness that is a product of low emittance, high average current and use of long undulators. As a consequence of the low emittance, a short electron beam lifetime is anticipated. Hence the ring will be designed to operate in the top-off injection mode maintaining the ring current of 500 mA distributed over ~1100 bunches with the accuracy of 0.5%. This will be accomplished by injecting trains of bunches (40-150 bunches per train) once per minute. Possibilities in realization of various camshaft and complex bunch patterns are being explored.

Alternative injector configurations were evaluated in the context of the project and included optimization of performance, investment cost, operating cost, and an assessment of risks for the project. A 3 GeV linac was considered, but was felt to incur too much risk and cost to the project. Serious consideration was given to an injector based on a booster sharing the same tunnel as the storage ring (in-tunnel booster) and to a more conventional configuration with a booster housed in a separate building (compact booster).

In this paper we discuss the current status of the design, parameters and lattices as well as the technical attributes of the both injector design options.

LINAC

The NSLS-II linear accelerator [4] must produce a substantial amount of charge with small emittance and energy spread (Table 1).

Parameter	Value
Energy	170-270 MeV
Emittance, X/Y, $4\beta\gamma\sigma_x\sigma_{x'}$	100 mm·mrad
Energy spread, single bunch	±0.5%
Energy spread, multi-bunch	±1%
Bunch train length	40-150 bunches, 2 ns
Bunch charge, single bunch	from 10 pC to 2.5 nC
Bunch charge, multi-bunch	<15 nC total

Table 1: Summary linac beam parameters

Recently electron linacs have become turnkey procurements (see for example refs 5&6). However, none has been delivered to date that provides the entire range of parameters required for NSLS-II operations. Of particular interest to NSLS-II is a flexible pulse format that allows multibunch injection with charge adjusted to provide the desired charge to bunches stored in the ring. Development of the techniques and hardware to accomplish this objective will be the subject of ongoing R&D activity for NSLS-II.

INJECTOR WITH IN-TUNNEL BOOSTER

The concept of placing the booster in the same tunnel as the storage ring was suggested and successfully implemented at the Swiss Light Source (SLS) [7]. The main advantages of such a layout are in the low cost of lattice elements, low power consumption, and excellent output beam properties. The main disadvantages are an inability to service the booster independently from the main ring, and the potential impact of stray fields from the ramping booster magnets on beam orbit in the storage ring.

The in-tunnel booster lattice for NSLS-II incorporates 60 gradient dipoles, with additional focusing magnets. The booster magnets are arranged to avoid physical interference with the storage ring straight sections (Fig. 1) where insertion devices will be installed. As a consequence, the symmetry of the booster lattice is identical to that of the storage ring. A single period consists of only a small number of magnetic elements, similar to that of the existing NSLS booster [8].

Two alternatives were considered for placement of the NSLS-II booster with respect to the storage ring. In the SLS design, the booster is positioned on the inner wall of the storage ring tunnel. In the NSLS-II, the booster would be placed 1.5 m above the main ring. This is adequate to avoid interferences with the ring subsystems and yet still allow easy access to the booster elements for installation and commissioning.

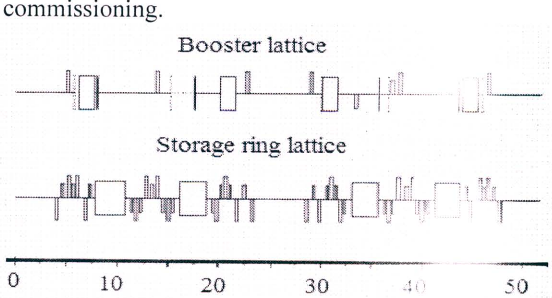

Fig. 1: Layout of the in-tunnel booster placed above the storage ring.

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The booster lattice is shown in Fig. 2. The lattice is designed with twelve identical cells and three modified cells containing families of quadrupole correctors. Phase advances per cell are chosen as 74° and 40° for horizontal and vertical planes, respectively. This results in a low horizontal emittance of 11.5 nm-rad at the nominal energy of 3.0 GeV.

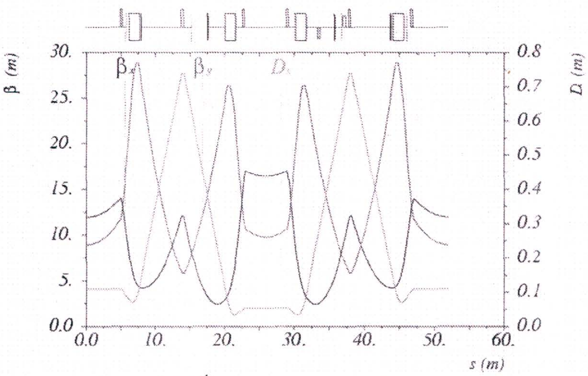

Fig. 2: 1/15th of the in-tunnel booster lattice

Chromaticity correction is implemented by introducing two sextupoles per booster super-period. Optimization of the Dynamic Aperture has led to a sufficiently large value: the developed lattice has a momentum aperture of about ±3% together with a DA of 190 mm-mrad (H) and 140 mm·mrad (V). Chromaticity driven by the Eddy currents was estimated to be sufficiently small (+0.3 x, -2 y) and could be compensated by modification of the sextupole ramp.

Table of the NSLS-II in-tunnel booster parameters and that for the SLS booster is shown below.

Parameter	SLS	NSLS-II
Energy range [GeV]	0.1 – 2.4	0.2 – 3.0
Circumference [m]	270	780
Emittance [nm-rad]	9	11.5
Repetition rate [Hz]	3	1
Rad. loss per turn [keV]	233	500
RF frequency [MHz]	500	500
RF voltage [MV]	0.5	1.0
RF acceptance [%]	±0.43	±1
Beam current [mA]	1	6
Momentum compaction	$5x10^{-3}$	$5.7x10^{-4}$
Tunes: x, y	12.41, 8.38	19.19, 10.73
Chromaticity: x, y	–15, –12	–21.7, –21.7
Damp. Time: x,y,E [ms]	11, 19, 14	22, 31, 19

Table 2: NSLS-II (3 GeV) and SLS (2.4 GeV) booster lattice parameters.

The repetition rate of the booster was chosen to satisfy the injection requirements and maintain low power consumption. We set the value of the booster vacuum to be 10^{-7} Torr or lower on average, providing an elastic gas scattering lifetime of 3.5 seconds at injection energy, and inelastic gas scattering of more than 15 minutes throughout the energy ramp.

INJECTOR WITH COMPACT BOOSTER

At the present time, compact booster designs [[illegible], 10, 11, 12] are well developed and demonstrated in installations around the world. For the purposes of this paper perhaps the most convenient reference design with a small emittance at 3 GeV is the injector designed by Danfysik and implemented at Australian Synchrotron Project (ASP, [13]). Following the ASP booster design we developed a conceptual FODO lattice for NSLS-II (Fig. 3). Its design is summarised in Table 3 in comparison with the original ASP solution:

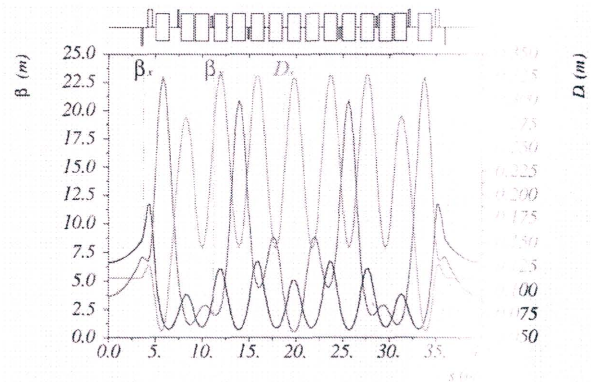

Fig. 3: ¼ of the compact booster lattice

During the design we set the booster circumference to 158.4 meters (1/5th of that of the storage ring for easy synchronization), providing 7.5 m long straight sections. We further bounded the maximum dipole field at 1T to provide headroom and allow for potential future energy upgrades. In addition quadrupole doublets were introduced in the straight sections for enhanced tunability of the lattice functions.

Parameter	ASP	NSLS-II
Energy range [GeV]	0.1-3.0	[illegible]-3 (3.6)
Circumference [m]	130.2	158.4
Emittance [nm]	34.4	26.6
Repetition rate [Hz]	3	1
RF frequency [MHz]	499.654	[illegible]99.654
RF voltage [MV]	1.2	1.2
RF acceptance [%]	0.66	0.91
Tunes: x, y	9.2/3.25	[illegible]1/6.69
Chromaticity: x, y	-8.83/-11.5	[illegible]/-18.9
Beam current [mA]	5	28
Momentum Compaction	0.0098	0.0072
Rad. loss per turn [keV]	743	625
Damp. Time: x,y,E [ms]	2.7/3.5/2.0	[illegible]/5.1/2.5
Damp. energy spread [%]	0.094	0.078
Damp. bunch length [mm]	19	13.9

Table 3: NSLS-II and ASP booster lattice parameters at 3 GeV.

Designing the injection and extraction systems (which will be discussed elsewhere) we kept in mind possibility of stacking bunch trains into the booster at the injection energy. The same considerations regarding repetition rate and booster vacuum were applied to both booster configurations.

Of course the compact booster requires its own stand alone enclosure. For design development and evaluation of comparative costs, a structure with a concrete tunnel 3-meter wide 2.4 meter height tunnel was considered. The structure was designed to utilize earthen bermworks to provide adequate shielding for worst case injector losses anticipated.

TRANSPORT LINES AND RING INJECTION STRAIGHT SECTION

Transport lines differ substantially for the two cases considered. For the in-tunnel booster case the transport line descends from the ceiling by a combination of two horizontal achromatic bends separated by a vertical achromatic dog-leg. In the compact booster case we are designing a layout with achromatic bend and a dog-leg. The transport lines are discussed in detail elsewhere [14].

Storage ring injection will occupy one of the 8-meter long straight sections. It consists of a non-interleaved orbit bump realized by four kickers, septum and pre-septum (Fig. 4 and Table 4).

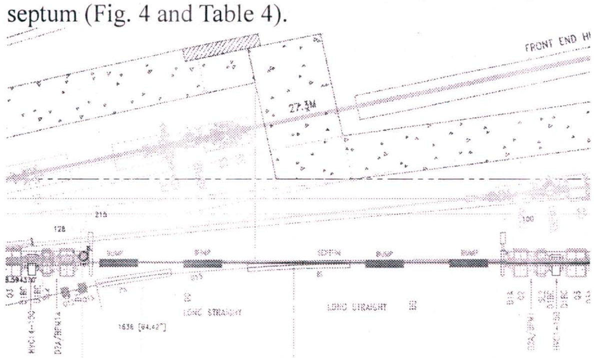

Fig. 4: Injection straight section layout

We are considering including two weak kickers for compensation of the bump mismatch and septa transients.

Parameter	Value
Kickers	
Length, cm	50
Field, T	0.18
Angle, mrad	9
Kicker pulse length, μs	5.0 (2 turns)
Septum	
Length, m	2
Field, T	0.4
Angle, mrad	80
Pre-Septum	
Length, m	1.5
Field, T	0.8
Angle, mrad	120
Waveforms	Full sine

Table 4: Parameters or the pulsed magnets in the ring injection straight section.

CONCLUSIONS

The NSLS-II injector must enable fast filling of the storage ring as well as the ability to maintain high ring current by using multiple bunch trains with flexible format. This will require high reliability as well as high performance in the selected injector option. As a part of the NSLS-II injector evaluation, we developed conceptual designs for in-tunnel and compact booster configurations. In operation, the two configurations were deemed to provide adequate reliability and performance as the injector for NSLS-II. The main difference between the options is the additional construction cost of the compact booster, which is substantially affected by the necessity of a separate building in which it is housed [15]. Offsetting this advantage for the in-tunnel booster is the risk associated with interferences in installation and maintenance that come from sharing the storage ring enclosure. In the context of the NSLS-II project, mitigation of this extra risk was deemed sufficiently important to offset the additional investment costs, thus, current NSLS-II injector is based on a low-emittance booster design located in the separate building.

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